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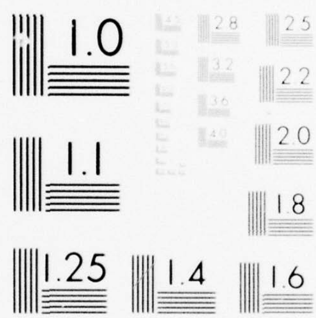
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RADC-TR-77-263, Volume I (of three)
Final Technical Report
August 1977

UNATTENDED/MINIMALLY ATTENDED RADAR STUDY
Executive Summary

General Electric Company

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, New York 13441

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APPROVED: Adrian S. Briggs

ADRIAN S. BRIGGS
Project Engineer

APPROVED: Joseph L. Ryerson

JOSEPH L. RYERSON
Technical Director
Surveillance Division

FOR THE COMMANDER: Carlo Crocetti

CARLO P. CROCETTI
Chief, Plans Office

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Executive Summary is a very short synopsis of the Unattended/Minimally Attended Radar Study to investigate the exploratory and advance development activities necessary to support the development of Unattended and Minimally Attended Radars. The study looked at several 2-D and 3-D radar designs. The primary considerations were high reliability and low-life cycle cost, with the additional constraint that the 2-D Unattended Radars were to use no more than approximately 500 W of prime power.

The conclusion of the study is that the technology is available, in 1977, OVER

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to permit development of Unattended (for 1 to 3 months) 2-D radars and Minimally Attended (3 radar maintenance men) 3-D Radars. Designs are discussed in the report which permit the 2-D radar to perform its mission while utilizing only 400 W of prime power.

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PREFACE

This report, prepared by the General Electric Company for Rome Air Development Center under Contract No. F30602-76-C-0380 was compiled by T. B. Shields, the Study Director. Major contributors were S. E. Bell, M. I. Fox, L. D. Hayes, R. V. Jackson, R. D. King, J. W. Krueger, D. J. Murrow, J. A. Rougas, N. A. Schmitz, F. D. Shapiro, J. J. Stewart, and R. D. Wengenroth. B. Cameron was the General Electric Company Program Manager. R. A. Ackley and A. S. Briggs were the RADC Program Monitors.

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GLOSSARY

CCD	Charge Coupled Device
CFAR	Constant False Alarm Rate
CRT	Cathode Ray Tube
DEW	Distant Early Warning
FOC	Final Operating Capability
GP	General Purpose
h	Hour
IF	Intermediate Frequency
IFF	Identification Friend or Foe
I/O	Input/Output
IOC	Initial Operating Capability
LFM	Linear Frequency Modulation
LSI	Large Scale Integration
MIPS	Million Instructions Per Second
MTBF	Mean Time Between Failures
MTTR	Mean Time To Repair
nmi	Nautical Miles
PM/FD&L	Performance Monitoring/Fault Detection and Location
RF	Radio Frequency
R/M/A	Reliability/Maintainability/Availability
SIF	Selective Identification Feature
SOW	Statement of Work

EVALUATION

The effort reported is one of three parallel study contracts performed under Project E233 by direction of ESD/XR. These reports identify alternative concepts and activity necessary to support the development of a short-range, unattended radar and a long-range minimally attended radar. The short-range radar is being viewed for application in DEW Line to replace the AN/FPS-19 and the long-range radar is being viewed for application by the Alaskan Air Command to replace the AN/FPS-93. These studies provide the assurance that current technology can support the development of unattended/minimally attended radars that offer improved performance and can significantly reduce operating and maintenance costs.

These efforts were performed in accordance with 1978-1982 TPO III, Thrust C Advanced Sensor Technology. The results will be used by ESD to develop system acquisition strategy for SEEK FROST (Project 2448), PE 12412F. It also provides supplemental data supporting SEEK IGLOO (Project 968H), PE 12325F.

Adrian S. Briggs

ADRIAN S. BRIGGS
RADC Project Engineer

SECTION I

INTRODUCTION

1. OBJECTIVE AND SCOPE

The primary objective of this study was the determination of those exploratory and advance development activities, including technology, component, and subsystem developments necessary to support the development of unattended and minimally attended radars. In support of this objective, design trades were performed to optimally configure two classes of radar sensors subject to the constraints specified in the Statement of Work (SOW). The first class is a short-range (instrumented to 60 nmi), 2-D, unattended radar with growth capability to 3-D. The majority of the design effort was directed toward this design with emphasis on the 2-D rather than the 3-D growth configuration. The second class is a long-range (150-nmi and 200-nmi instrumented ranges), 3-D, minimally attended radar with growth to unattended. Minimally attended is defined as requiring a maximum of three-radar maintenance technicians per site.

The principal design ground rules include high-reliability, low-prime power, low-life cycle cost, and 1976 to 1980 technology. The unattended radar design goal of 3, 6, and 12 months of unattended operation with a probability of successful operation of 0.9 at the end of that period, translates to a minimum of two orders-of-magnitude increase in mean time between failure (MTBF) with respect to systems currently in the field. Likewise, the prime power design goal of 500 W for the unattended radar represents roughly an order-of-magnitude reduction from conventional designs. These, along with the low-life cycle cost emphasis, completely dominated the conduct of the study and resulted in the development of novel designs to best accommodate these goals. Finally, these design goals could not have been realized if off-the-shelf 1974 technology were specified. Furthermore, a large risk would be incurred if 1980 to 1985 technology were invoked since this technology extrapolation is speculative at best. It is only through technology advancements developed in the 1975 and 1976 time frame (such as charge coupled devices (CCD's), large-scale integration (LSI) of digital components, and microprocessors) that these design goals are determined to be achievable with an acceptably low risk.

2. CONDUCT OF THE STUDY

Figure 1-1 shows the design process flow. The system design process steered the other design activity emphasis to those areas that are responsive to the overall requirements. This was accomplished through allocation of system requirements by informal specifications. In addition, the alternative designs were limited to that range of candidate technologies which fit the reliability and performance requirements.

The process flow was triggered by the systems requirements generation activity, as shown in Figure 1-1. The inputs to this initial effort were provided primarily through the SOW and subsequent customer guidance.

The alternative systems concepts definition provided an initial cut at applicable designs and narrowed the candidate technology to that which is responsive to the initial requirements.

The initial performance/reliability and maintainability (R&M) evaluation was performed on this set of concepts to limit the number of candidates considered in the detailed design phase. The detailed design and evaluation consisted of blending the candidate concepts parameters with the subsystem-*requirements*-driven applicable technology to derive the detailed candidate designs as shown in Figure 1-1. This activity resulted in selected design approaches which were refined by final technology selections to yield the final baseline system designs. These were then evaluated from the standpoint of R&M and life-cycle cost optimization.

The study emphasis and effort was concentrated to a large extent in the areas of critical technology evaluation and developing "design for reliability" approaches since the key to extended operation without maintenance at reasonable initial investment costs is the combination of near-term technology with creative implementation techniques.

Figure 1-2 depicts a schedule of the design study elements. It is seen that the applicable technology and design option developments and iterations responsive to the reliability requirements dominated the study, as indicated previously, consistent with the overall study.

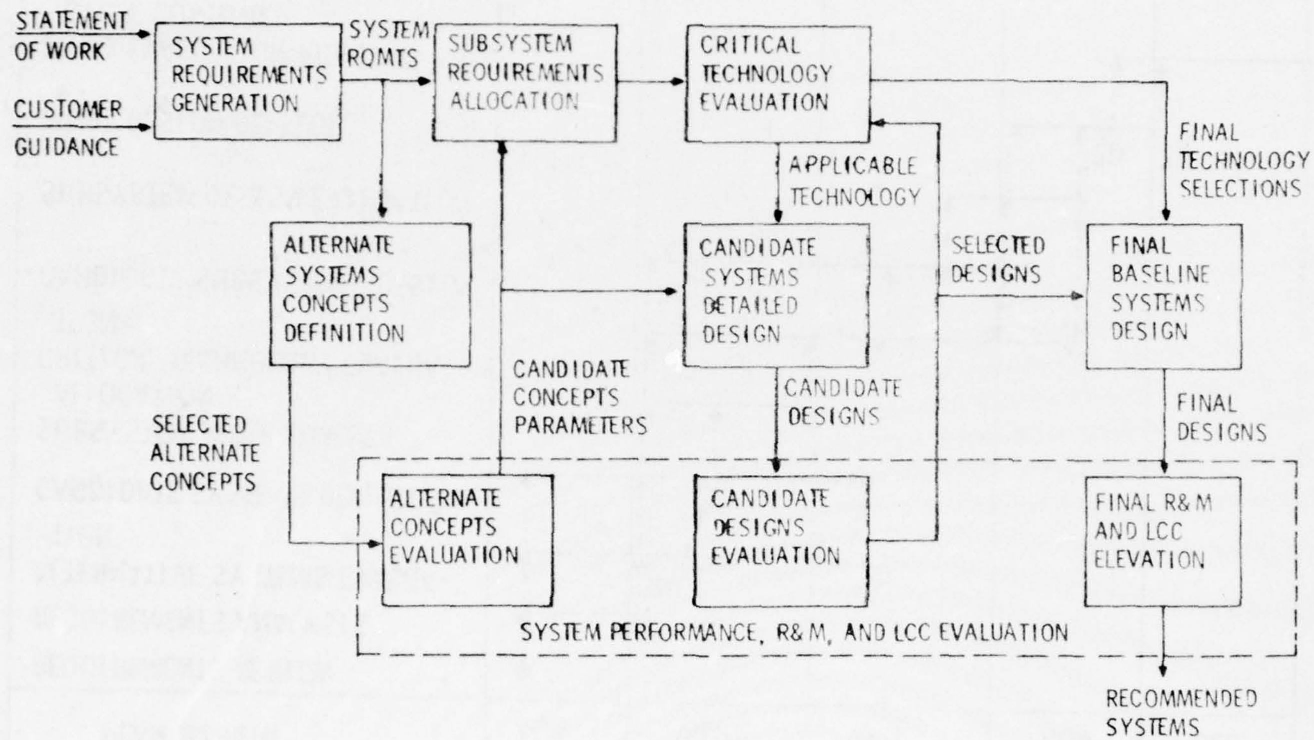

Figure 1-1. Design Process

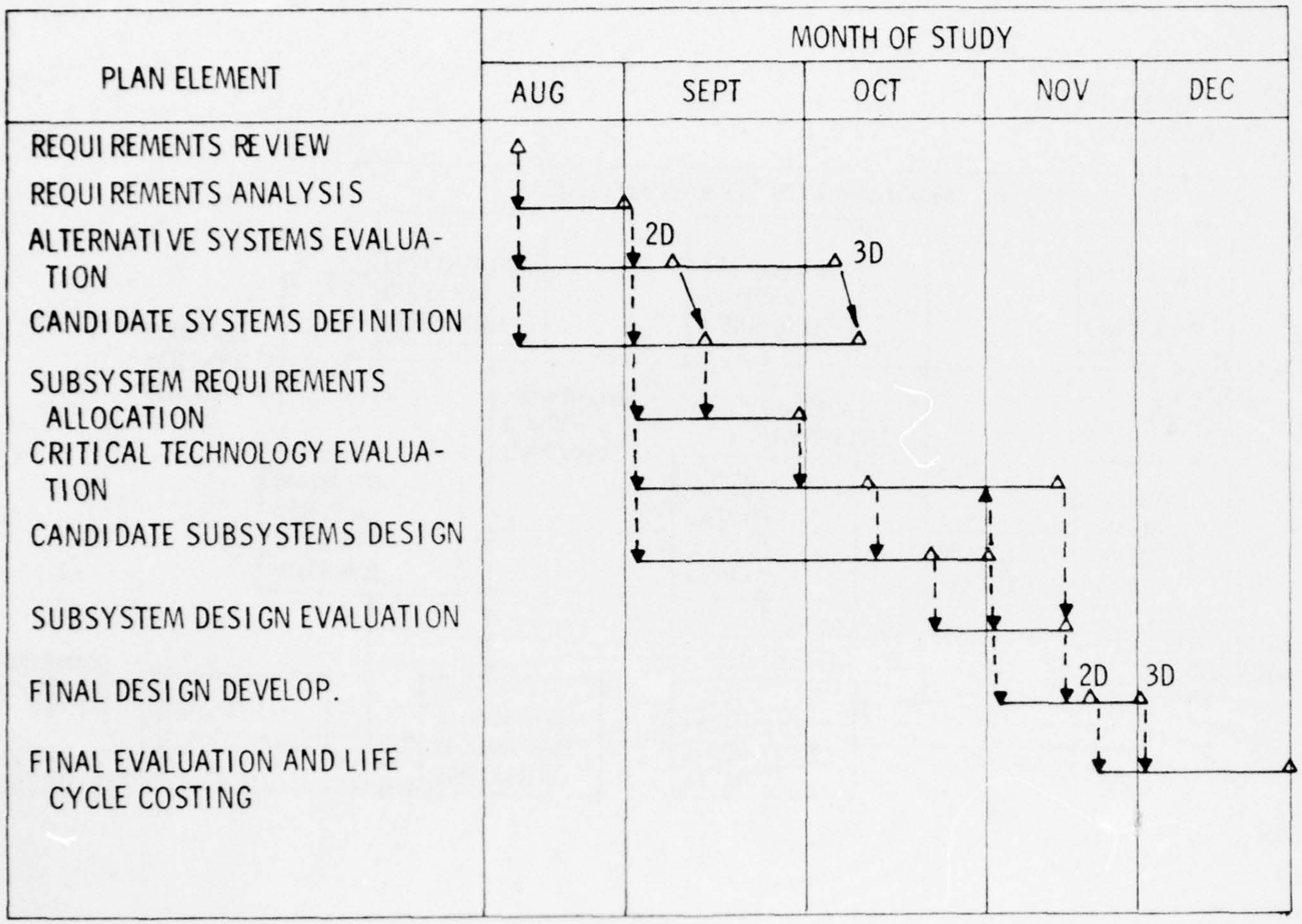

Figure 1-2. Design Study Schedule

SECTION II

2-D UNATTENDED RADAR DESIGN

1. CRITICAL ISSUES

The design options considered for the 2-D Unattended Radar design were primarily constrained by the ultra-high reliability necessitated by its unattended operation role and the limited prime power available. These constraints, coupled with the low-life-cycle cost emphasis, completely dominated the design.

The 500-W goal specified for the radar allocation was based on a preliminary budget of the total site power of 2 kW which also allocated 100 W to communications, 400 W to security, and 1 kW to environmental control. This budget limits the radar design options. It is recommended that this be reviewed to allow use of the heat energy formed as a by-product in the prime power generation process to be utilized for environmental control and thereby make available part of the 1 kW currently allocated to environmental control. Because of the severe prime power limitation, standard-design procedures (such as power-aperture cost optimization) do not apply. As a result, antenna sizes and costs are larger than conventional designs of similar performance capability. In spite of this, highly efficient design options were developed which fit roughly within the 400 W to 1 kW dc prime power window.

The other dominant issue is that of reliability as it relates to unattended operation. The design goal consisted of providing a probability of successful operation of 0.9 after 3, 6, and 12 months of unattended operation. For conventional system designs, this correcponds to a MTBF of approximately 20,000 h for the 3-month unattended period. This, in turn, is roughly two orders-of-magnitude beyond systems currently in the field. Through the use of selective redundancy, high-reliability components, and state-of-the-art technology, the recommended radar design provides these quantum jumps in reliability. However, none of the designs considered can achieve the specified probability of successful operation for 6 or 12 months on a single radar basis. However, the radar network can be successfully operated if contiguous sites are not failed. Therefore, unattended operating periods of 6 to 12 months can be achieved with these designs. It is recommended that a three month preventive maintenance period be specified. This allows substantial savings to be

realized by removing permanent personnel from the sites and avoids high-risk/ high-cost design options. The operational experience can then guide the maintenance philosophy to balance availability with cost in formulating the final preventive maintenance interval policy.

2. BASELINE DESIGN

The recommended 2-D Unattended Radar consists of an L-band integral Identification Friend or Foe (IFF) cylindrical array as shown in Figure 2-1. Note that the entire radar is contained in the fiberglass-reinforced Teflon radome module with the maintenance supply, living, and prime power shelters at ground level. The design features incorporated in this approach include excellent low-altitude detection in multipath; automatic detection and tracking; frequency diversity, coherent Doppler integration, and zero-Doppler detection for outstanding performance in both ground and weather clutter; and remote Performance Monitoring and Fault Detection/Location (PM/FD&L) from a manned maintenance node. Due to specific technology advances in the last two years in such areas as LSI digital devices, CCD's and microprocessors, these features are available with only one cabinet of equipment devoted to the signal and data processing functions. These technology advances simultaneously address both the prime power and realibility issues, allowing selective redundancy with modest costs and simultaneously providing dramatic reductions in required prime power.

The recommended design uses low-risk RF technology centered around low-power diode switches and amplifiers. The prime power constraint implies low-power devices which are inherently low risk. The antenna columns shown in Figure 2-1 are eight-element stripline feeds which form multiple beams that are weighted and summed to provide the 2-D coverage pattern. This approach also allows extension to 3-D by separate (either parallel or time-multiplexed) processing of the output beams. It is recommended that these be replaced by simpler horn or array feeds if growth to 3-D is not required, since the array dominates the RF costs due to the prime power limitation. Exclusive of array distribution and radiation, the entire RF and IF equipment is housed in a simple cabinet mounted in the radome.

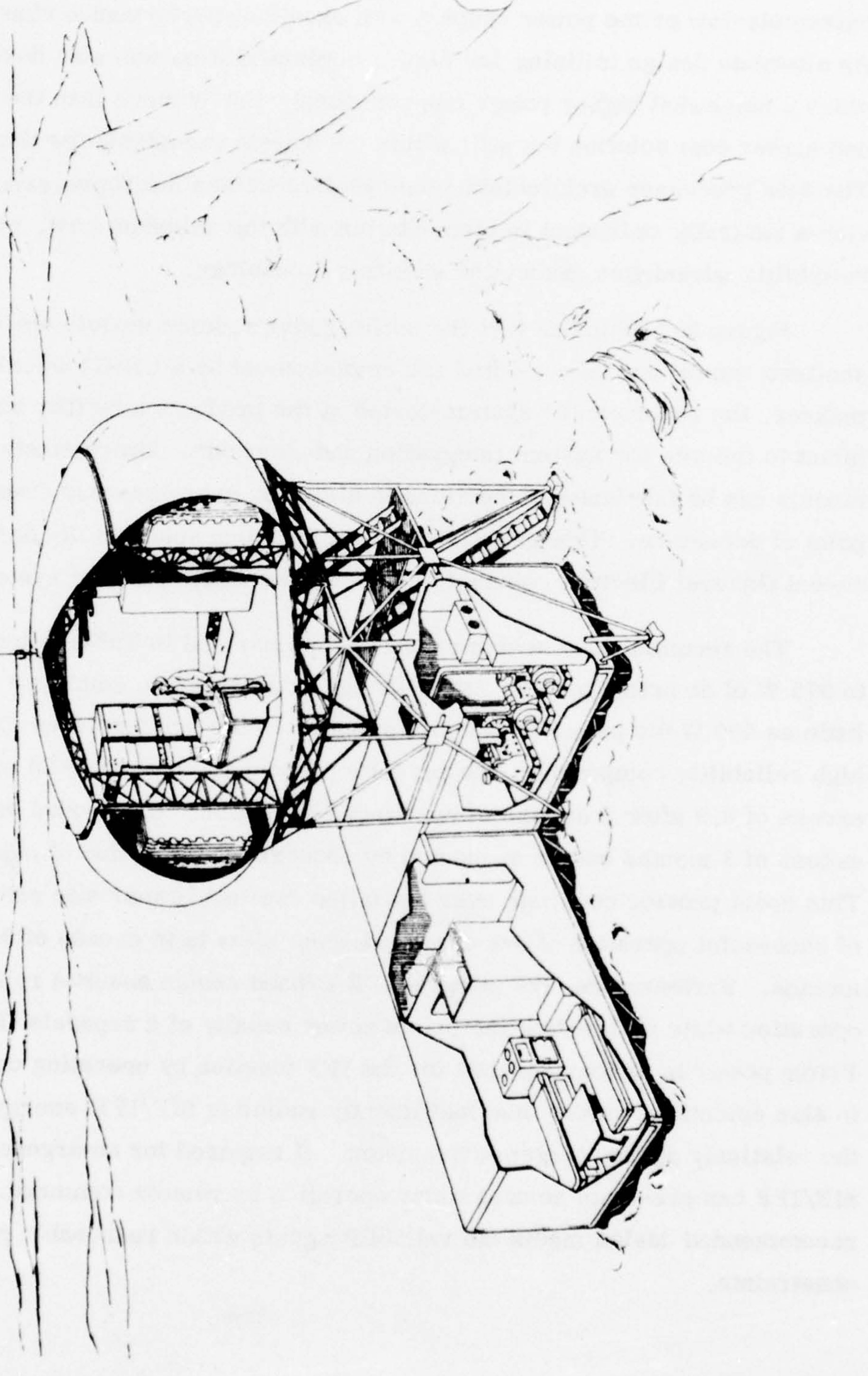

Figure 2-1. 2-D Radar Concept

The signal and data processing requires an additional cabinet also located in the radome. The recommended signal processor employs analog CCD's recently developed and tested by General Electric. This approach results in low cost and extremely-low prime power coupled with excellent performance characteristics. An alternate design utilizing LSI digital implementation was also developed and provides a somewhat higher power (approximately 100-W more than the CCD approach) and higher cost solution but still within the bounds acceptable for this application. The data processor architecture employs data-driven microprocessors which provide a naturally redundant implementation with the attendant cost, prime power, and reliability advantages associated with this technology.

Figure 2-2 indicates that the entire radar radome module (as well as other shelters shown) can be air-lifted for emplacement by a CH-53 helicopter. In this manner, the radar can be system-tested at the production facility and transported intact to the site for system integration and checkout. Alternatively, the radome module can be fabricated in sections to allow for over-the-road transportability to point of departure. This palletized design has been successfully demonstrated on a recent General Electric contract and avoids the inefficiency of system tear-down.

The recommended design approach summarized in Table 2-1 requires 440 W to 975 W of dc prime power. Other design options can be employed which use as little as 400 W for prime power minimization is the driving design parameter. With high reliability components, the per-site probability of successful operation is in excess of 0.9 after 3 months of unattended operation. Unattended periods well in excess of 3 months can be supported by resource reallocation of adjacent sites. This could provide coverage over the failed degraded radar site since the probability of successful operation of one of two adjacent sites is in excess of 0.9 after 10 months. Furthermore, the integral IFF L-band design assures reliable SIF/IFF operation while eliminating the prime power penalty of a separate IFF system. Prime power is further reduced for the IFF function by operating only in response to skin detections rather than inefficiently radiating SIF/IFF energy continuously in the relatively sparse target environment. If required for emergency use, the SIF/IFF can pre-empt normal radar operation by remote command. Thus, the recommended design meets the reliability goals within reasonable prime power constraints.

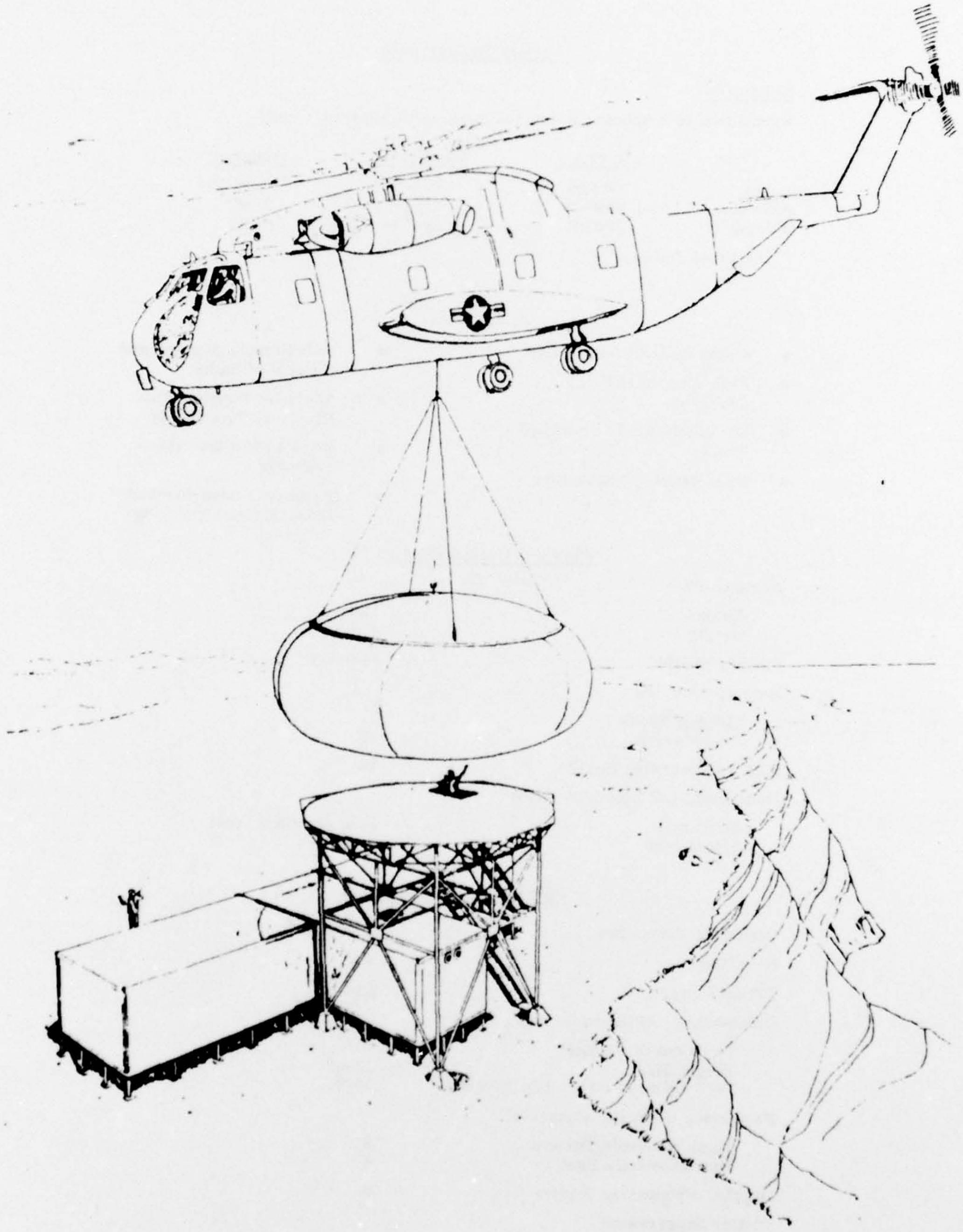

Figure 2-2. 2-D Radar Emplacement

TABLE 2-1. 2-D UNATTENDED L-BAND SOLID-STATE RADAR

System Performance

Reliability:

Probability of 3-month Unattended Successful Mission > 90%

	Coverage	Resolution	Accuracy*
Range	60 nmi	0.32 nmi	0.16 nmi
Azimuth	360°	3°	0.25°
Altitude	100 kft	csc^2 to 50°	N/A

* At Track Initiate

Advantages

- Single Radar Housing Unit
- Full Integral IFF/SIF Capability
- 20-Simultaneous Smoothed Tracks
- Solid-State Transceivers
- Full Remote Monitor and Control of Radar
- 32-Pulse Doppler Plus Diversity Processing
- 32: 1 LFM Pulse Compression
- Automatic Scan-to-Scan Detection and Tracking

Physical Characteristics

Antenna Size	
Radius	11 ft
Height	4.5 ft
System Weight	8000 lbs
Antenna Modules	
Column Feeds	32
Tranceivers	32
Signal Processing Boards	16
Distributed GP Data Processor	
Memory	155k (16-bit words)
Throughput	6 MIP's

Operating Characteristics

Operating Frequency	1215-1400 MHz
Scan Time	4 s
Prime Power	975 w*
Detection/Tracking to 60 nmi	
P_D (1 out of 4 scans)	95%
Target Size	16 m^2
Probability of False Track Initiate	10^{-6}
Frequency Diversity Channels	
Total Available/System	8
Simultaneously Used	4
Doppler Processing Filters	8
Clutter Suppression	
Ground	>50 dB
Weather	>32 dB
MTBF	24,155 h
MTTR	20 min

*440 W for 8 s frame time and 180° azimuth coverage
975 W for 4 s frame time and 360° azimuth coverage

3. SCHEDULE AND COST

A nominal development and production schedule is shown in Figure 2-3 wherein an Engineering Development contract phase provides for the development, fabrication, and testing of three preproduction units which are used to provide the design confidence and finalize the production designs prior to production go-ahead. Note that two preproduction systems are reserved for reliability testing. These, plus selected subsystem testing and analytical extrapolation, provide the required level of confidence prior to production release. This reliability testing represents an important departure from traditional methods and is necessitated by the extremely high specified reliability. Traditional methods of reliability testing would require many years of test to assure reasonable confidence levels.

Finally, the production phase includes the fabrication of the first production article, followed by a production rate of four units per month. This represents a reasonable rate without resorting to substantial investment in new production facilities. Furthermore, this rate is consistent with the projected Initial Operational Capability (IOC) and Final Operational Capability (FOC) spanning the 1981 through 1983 period. Since the total radar consists of two cabinets of equipment plus the RF components, reasonable variations around the four-unit per-month production rate can easily be accommodated. The optimum rate should consider total system costs including transportation, storage, and installation considerations. The conclusion reached in this study is that a high-performance low-risk unattended radar can be developed in the desired time frame at an affordable cost within reasonable prime power constraints.

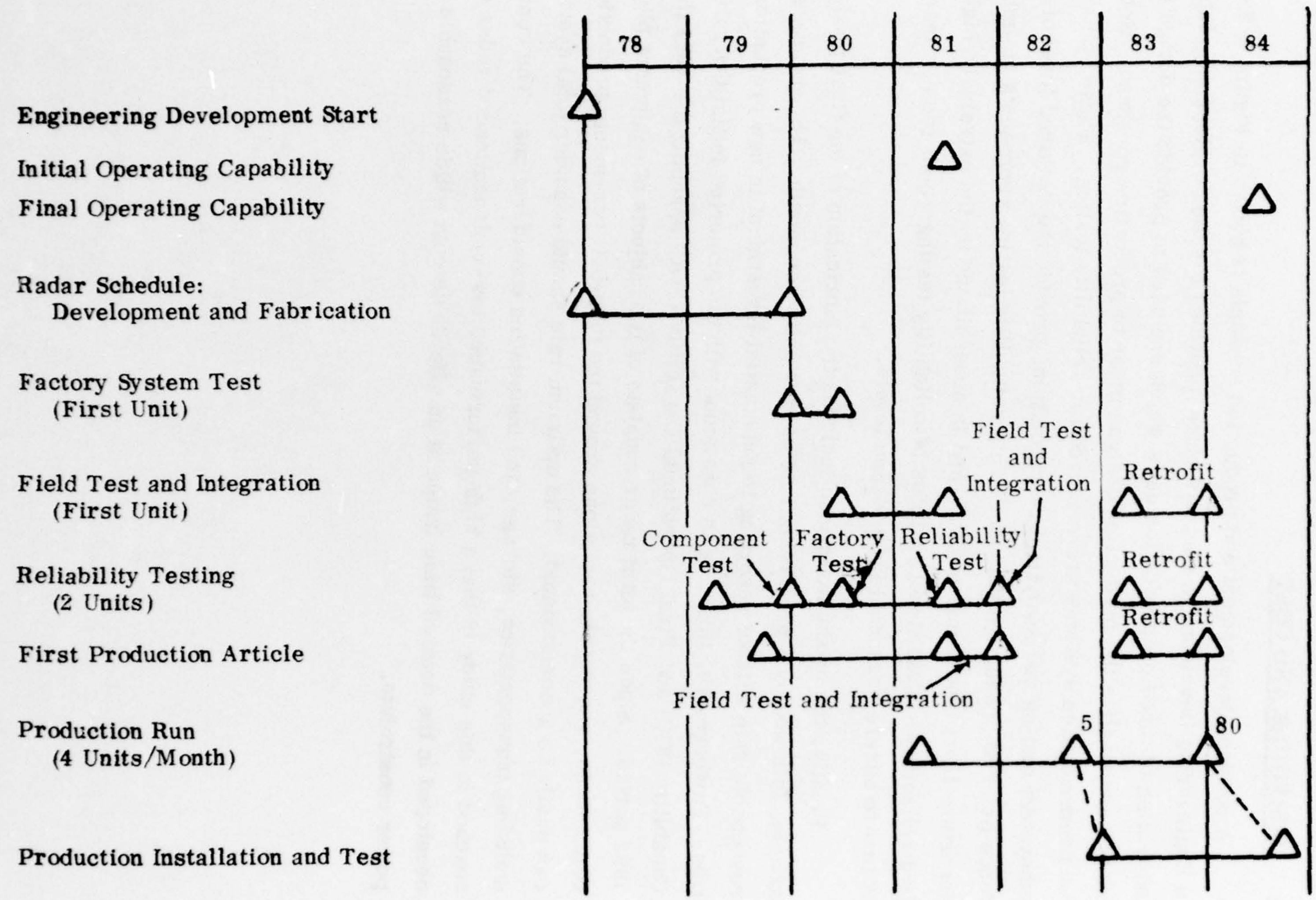

Figure 2-3. 2-D — Development and Acquisition Schedule

SECTION III

3-D MINIMALLY ATTENDED RADAR DESIGN

1. CRITICAL ISSUES

The issues of paramount importance to the 3-D Minimally Attended Radar design are summarized on Table 3-1. With respect to Reliability/Maintainability/Availability (R/M/A) requirements, the recommended design provides in excess of 1000 h MTBF. Also, the growth-to-unattended goal is specified as achieving a probability of successful operation of 0.9 after an unattended period of 15 days, 45 days, or 90 days. With no modifications, the recommended design provides this performance after a 5-day unattended period. Extension to at least the minimum period of 15 days would be accommodated by employing selective redundancy, increased reliability components, and (if cost-effective to achieve longer unattended periods) using the unattended radar signal and data processing architecture to provide increased self-healing capability.

TABLE 3-1. CRITICAL 3-D MINIMALLY ATTENDED RADAR ISSUES

R/M/A REQUIREMENTS
- MINIMAL MAINTENANCE
- GROWTH TO UNATTENDED OPERATION

DESIGN FEATURES
- LONG-RANGE HIGH-ALTITUDE COVERAGE
- AUTOMATIC DETECTION, IFF CORRELATION, AND 3D TRACKING
- ADAPTIVE CLUTTER PERFORMANCE

RADAR DESIGN CHALLENGES
- HIGH RELIABILITY SIGNAL/DATA PROCESSING
- GRACEFUL PERFORMANCE DEGRADATION
- AFFORDABLE INVESTMENT COST
- LOW-RISK TECHNOLOGY

The design features indicated on Table 3-1 are available in an existing design, the AN/TPS-59, and are also included in an internally-funded program to develop the GE-592 radar. These performance features have been demonstrated in extensive testing and shown to represent an effective approach to automatic search and track in a cluttered environment. This design provides full target detectability and Constant False Alarm Rate (CFAR) maintenance against strong ground and weather clutter and, most significantly, in a combined weather/ground clutter situation. It will maintain height accuracy with little degradation at elevation angles as low as 0.5°.

The R/M/A aspects of the radar design challenges are well addressed by the AN/TPS-59. The high reliability cited above is due in large measure to the fact that the radar is totally solid-state, including the transmitter. Power is generated directly at the L-band transmit frequency by high-power RF transistors. The radar Mean Time To Repair (MTTR) is 40 minutes, and both preventive and corrective maintenance can be accomplished by a minimum crew. The maintenance is simplified by use of the general-purpose control computer which performs automatic, continuous performance monitoring and automatic, off-line fault location.

2. RECOMMENDED 3-D RADAR DESIGN SOLUTION

The recommended design is an L-band air surveillance radar with an array antenna which electronically phase scans a pencil beam in elevation while continuously rotating in azimuth to provide real-time tri-coordinate data on all targets within the surveillance volume.

Figure 3-1 is a sketch of the system in its fixed site configuration. It shows the IFF antenna mounted atop the primary radar antenna within a standard 55-ft radome. The Processing Center is located in the tower.

The block diagram, Figure 3-2, shows an important departure from conventional radar design. All RF electronics (the subsystems shown above the horizontal dashed line) are mounted on the rotating array platform. Radar signals pass through slip rings at a 75 MHz IF (there is no rotary joint, except for IFF signals). The low-level radar signals, together with prime power and digital control and timing signals, are transmitted between the array platform and the Processing Center over interconnecting cables. Cables up to two miles in length can be driven; therefore, as a practical alternative, the array may be remotely operated up to two miles away from the Processing Center.

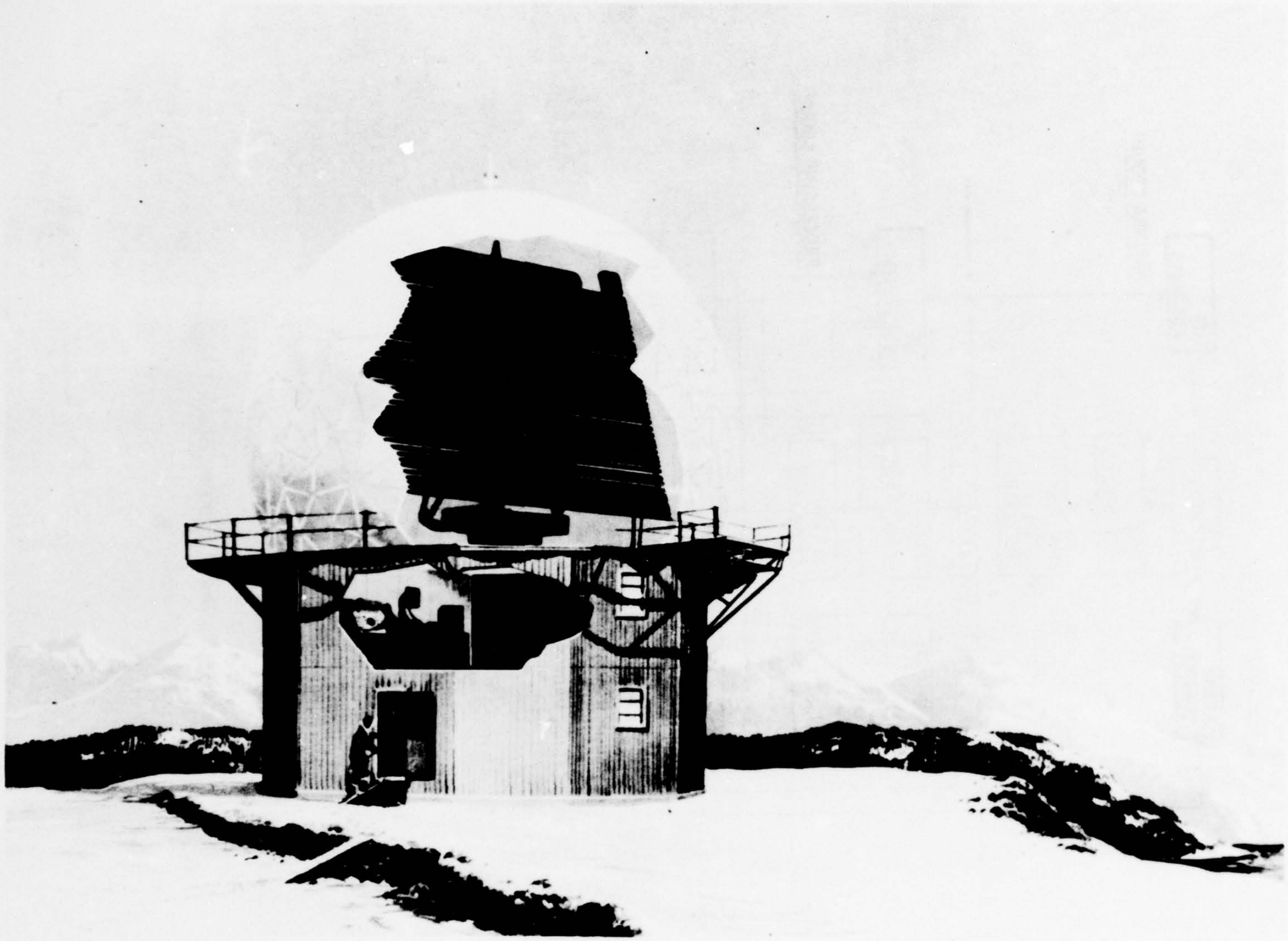

Figure 3-1. 3-D Radar Concept

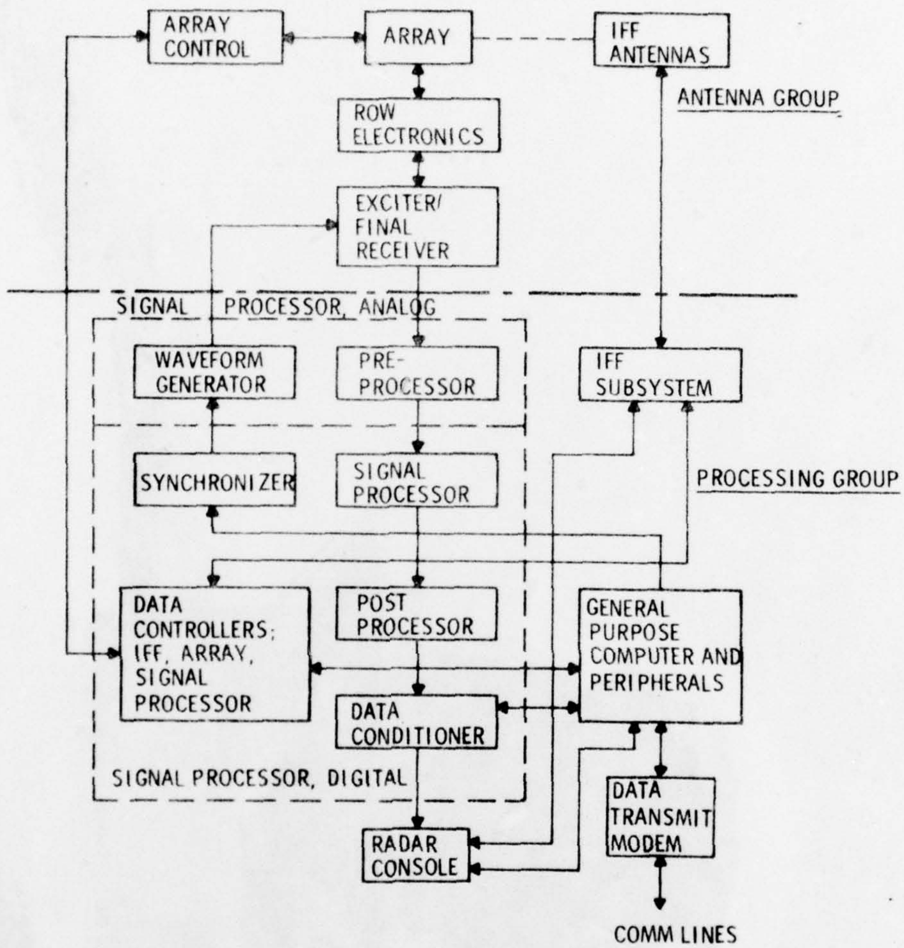

Figure 3-2. System Block Diagram

On the antenna platform, 44 horizontal passive linear arrays, or row feed networks, are stacked one above the other on 6.6-in. centers to make up the approximately 24-ft wide by 24-ft high planar array. Mounted directly behind each row feed is a distinct, dedicated transmitter-receiver (transceiver). The row transceivers perform all the RF functions, including RF power generation, phase shifting to steer the antenna beam in elevation, filtering to suppress out-of-band tranmissions and receptions, and preamplification to provide a low noise figure. The row transceivers are totally solid-state. The RF power is generated by direct amplification through L-band power transistors.

The Processing Center includes the signal processor, which is primarily digital equipment, the data processing subsystem, comprised of the GP radar control computer, its peripherals and special interface hardware, the maintenance console, and the IFF processing equipment.

The array may be operated unattended. Its performance is automatically and continuously monitored at the Processing Center to assure corrective maintenance when required. Array reliability is high enough to assure proper operation with maintenance actions (either corrective or preventive) at intervals of not less than one to two months. Because of the high degree of redundancy provided by the distributed electronics, emergency corrective maintenance on the array will almost never be required.

Prominent features of the 3-D minimally-attended L-band radar recommended by the General Electric Company are summarized in Table 3-2.

TABLE 3-2. 3-D MINIMALLY ATTENDED L-BAND RADAR

System Performance

	Coverage	Resolution	Accuracy
Range	200 nmi/150 nmi	0.4 nmi	1500 ft
Azimuth	360°	2.25°	0.3°
Altitude	100 kft	2.15°	2000 ft at 100 nmi

Advantages

- Full IFF/SIF Capability
- Track-While-Scan Processing
- Unattended Operation Capability
- Remoted Array Optional
- Remote Performance Monitoring
- Flexible Data Output Interface

Physical Characteristics

Antenna Size	
Height	24 ft
Width	24 ft
Rotating Weight	5140 lbs
Radome	CW-860 or equivalent
Prime Power	51.1 kW (200 nmi design) 48.3 kW (150 nmi design)
Standard Antenna Modules	
Feed Networks (Row)	44
Transceivers	44

Parameters

Scan Time	12 s
Detection Probability at 450 km (Single Scan)	
P_D	90%
Target Size	1 m^2
False Alarm Rate	< 3/scan
Clutter Suppression	
Ground (Simultaneous)	> 50 dB
Weather (Simultaneous)	> 34 dB
MTBF	1000 h
MTTR	50 minutes

3. OPERATIONAL CONCEPT

It is envisioned that the 3-D Radar will be used primarily as a sensor providing three-dimensional radar and IFF data to an Operations Center. A radar operator is not required for this purpose and, in fact, an operator's display console is not provided in this configuration. All radar and IFF video, digital data on detected targets, and control and status signals required to operate the radar are transmitted via coaxial cable to an Operations Center.

A maintenance console is incorporated. It includes a PPI display with readouts and controls adequate to permit accurate assessment of radar output data quality, and an alphanumeric CRT terminal for communicating detailed performance status and fault location data. The CRT terminal is also the man/machine interface through which system initialization and infrequent operational parameter changes are accomplished.

The application of a general purpose computer as the radar controller allows adaptability of the radar to a variety of missions. Waveform selection, beam positions, dwell times and processing configuration can be adapted to changing conditions by means of data entries in a stored table. Interface with other systems is accomplished through the computer Input/Output (I/O) to allow matching system requirements by changing word formats.

A very important aspect of the use of the general-purpose computer to provide interface data is that it allows growth of the 3-D radar system to unattended operation. Two-way communications are possible. Commands can be sent to the general-purpose computer for execution and response. In addition performance data can be continuously provided from the radar to the operations center for continuous monitoring.

4. SCHEDULE AND COST

Cost estimates were prepared for the development, testing, and production of 20 3-D minimally attended radars. Costs were generated for both the 200 mni version and the 150 nmi version.

Figure 3-3 shows a schedule for these radars. The Engineering Development phase provides all of the nonrecurring engineering and manufacturing effort to build and test the first system and prepare for production of the remaining 19 systems. The production rate is one per month.

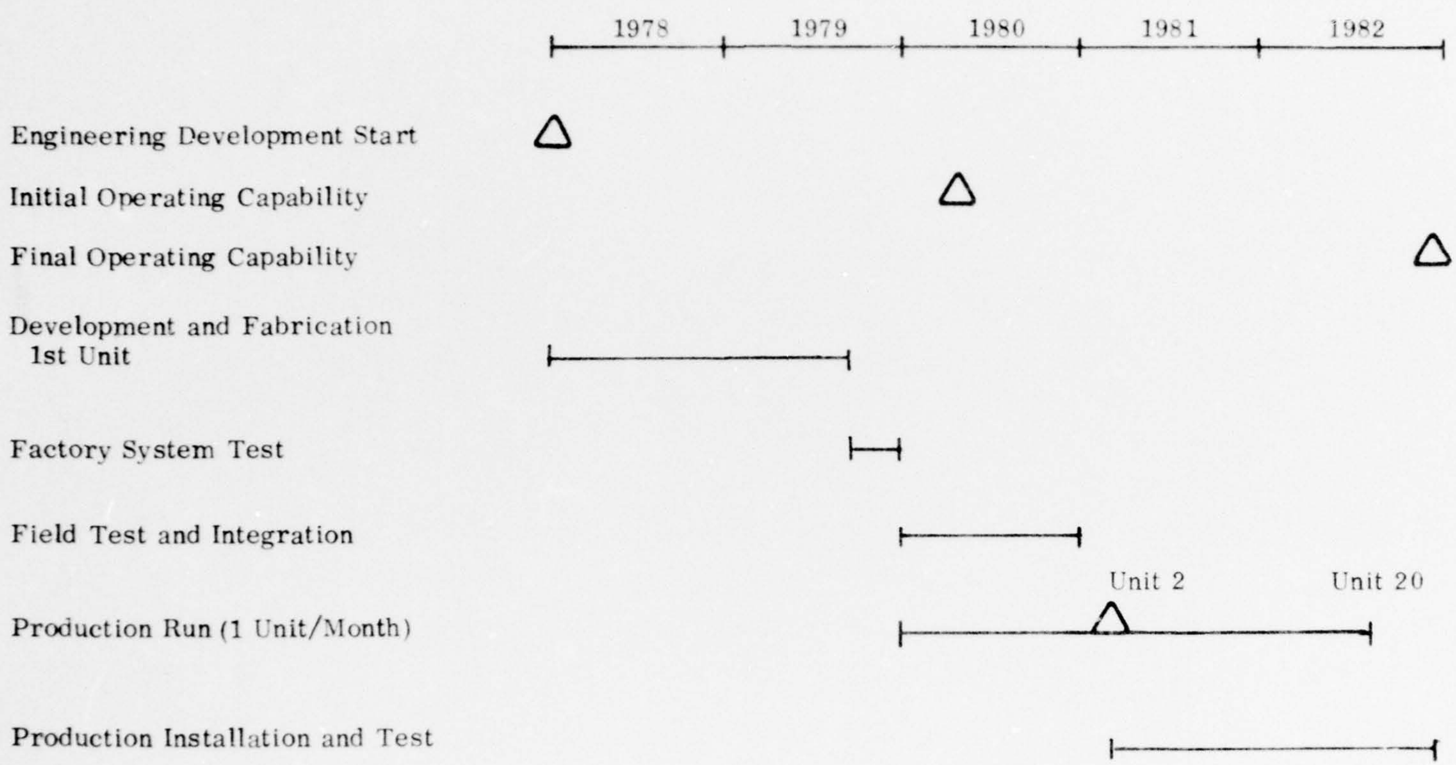

Figure 3-3. 3-D Development and Acquisition

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RADC plans and conducts research, exploratory and advanced development programs in command, control, and communications (C^3) activities, and in the C^3 areas of information sciences and intelligence. The principal technical mission areas are communications, electromagnetic guidance and control, surveillance of ground and aerospace objects, intelligence data collection and handling, information system technology, ionospheric propagation, solid state sciences, microwave physics and electronic reliability, maintainability and compatibility.

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